Reflex and Non-Reflex Torque Responses to Stretch of the Human Knee Extensors

N. Mrachacz-Kersting, T. Sinkjaer

Center for Sensory-Motor Interaction (SMI), Aalborg University, Aalborg, Denmark

***Abstract* – Reflex responses to unexpected stretches are well documented for a range of muscles in both animal and human. Moreover, investigations of their possible functional significance, has revealed that reflexes can contribute substantially to the overall stiffness of a joint. Unfortunately due to obvious technical limitations, only the muscles spanning the human ankle joint have been investigated in the lower extremity in the past. This study implements a unique hydraulic actuator to study the relative contributions of the knee extensor stretch reflex to the overall knee joint stiffness. The quadriceps muscles were stretched at various background torques, produced either voluntarily or electrically and thus the purely reflex-mediated torque could be calculated. The contribution of the reflex mediated stiffness initially low, increased with increasing background torques for the range of torques investigated.**

***Keywords*: Stretch reflex, Mechanical stretch response, Electromyographic stretch response, Human quadriceps muscle**

I. INTRODUCTION

Both human and animal reflex responses to sudden and unexpected changes in muscle length are well documented in the literature [for a review see 1] [2] [3]. The role of the reflex is still controversial, but it has been suggested that not only does it increase muscle and thus joint stiffness, but it also allows for a more uniform stiffness over a diverse range of the muscles physiological operating lengths and tension. In the cat the reflex mediated stiffness has been shown to be independent of changes in muscle length [4], indicating that the short latency reflex may be controlled by muscle and / or joint stiffness rather than by purely muscle length changes. For simplicity purposes, muscles spanning the ankle joint may have received the most attention in the human. The relative contributions of non-reflex and reflex mediated stiffness have been well documented for the ankle extensors [5] [6] and flexors [7]. During low ankle extensor contraction levels, up to two thirds of the total stiffness arose from the reflex mediated stiffness when measured 200 ms after stretch onset [5] [6].

Although the electromyographic (EMG) stretch reflex of the knee extensors has been described in the past [8] [9] its importance from a mechanical point of view has only been investigated in the cat [10]. The aim of this ongoing study was to examine the relative contributions of the quadriceps reflex mediated stiffness to the total stiffness of the knee joint at various background torques.

II. METHODS

Three healthy subjects aged 22 to 31 years participated in the study. All subjects gave their informed consent.

1) *Apparatus:* The subjects were seated on a fixed chair with the hip at 90° and the knee at 130°. The left leg was affixed to a PID controlled hydraulic actuator (MTS-systems Corporation 215.35 [11]), such that the anatomical knee axis of rotation was closely aligned with the center of rotation of the actuator. This ensured that any movement at either the hip or ankle joint due to the rotation of the knee joint was kept at a minimum such that stretch reflexes were elicited solely in the knee extensors. The slight oscillations observed in the torque traces of Fig. 1 and Fig. 3 respectively, may reflect that very slight movements in the ankle and hip joint were unavoidable. The foot and leg segments of the left leg of the subject were firmly strapped to a custom-made plate, which extended out from the actuator, via velcro straps, producing a tight interface between the arm of the motor and the leg of the subject. The plate was instrumented with an accelerometer (Kistler, Piezotron) and a load cell (Kistler, Slimline), which was used to trace the force from the knee extensors. The force was later converted to torques by inclusion of the moment arm. The position of the rotary actuator was monitored with an angular displacement transducer (Transtek DC ADT series 600).

2) *Data Collection:* During both voluntary contraction and electrical stimulation trials, the actuator applied stretches of a 20° amplitude and a rise time of 300 ms, producing a stretch velocity of 67 °/s. The torque exerted on the plate by the subject was displayed on an oscilloscope. Initially, a maximal voluntary contraction (MVC) of the quadriceps was performed to determine the maximum possible force, which the subject can voluntarily exert on the plate. A suitable position for stimulation, defined as the site where a maximal M-wave was produced in the RF with minimal activity from the synergists vastus lateralis (VL) and medials (VM) and no activity from the antagonists biceps femoris (BF) and the medial hamstrings (MH), was located. Palpitation of RF, VL, VM, BF and HM muscles was performed during stimulation trials to ensure that this was occurring. Following this the femoral nerve was stimulated in the femoral triangle using 1 ms squared pulses at a frequency of 1 Hz, from a constant current isolated stimulator (Axon Isolator-11). This was used to indicate the maximum M-wave for the RF (M-max). To be able to measure the intrinsic force increment, the pulse frequency was increased to 20 Hz. This ensured that a fused contraction of the RF was

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produced which exerted a constant force on the plate. Five consecutive stretches were now applied at the knee joint while the EMG, force and position data were collected. The peak-to-peak M-wave was monitored on-line to ensure a constant stimulus to the RF muscle as well as to monitor possible activation of synergistic muscles. To attain various force levels, the stimulus intensity was varied manually for each following trial. Depending on the subject, five to eight force levels were attained in this way. Trials where the peak-to-peak M-wave varied were discarded, as were trials where the antagonists showed activation. From time to time a H-reflex appeared with the M-wave. These trials were not discarded, except if the H-reflex varied in amplitude, as it is believed that the intrinsic properties of a muscle activated by a H-reflex do not differ from when it is activated by a M-wave [1].

To determine the total force increment, the above trials were repeated while the subject was asked to voluntarily re-produce the forces attained during the electrical stimulation. This was done, by asking the subject to maintain the relevant constant force signal as displayed on an oscilloscope.

Pairs of surface electrodes (Medicotest 720-01-K) were used to record the EMG of RF, VL, VM, BF and HM of the left leg. The electrodes were placed following the recommendations of Garland et al. [13]. The EMG signals were amplified and high-pass filtered at 20 Hz (Butterworth 1st order digital filters with no phase lag), and in some cases rectified and first-order low pass filtered at 20 Hz. All data was sampled at a frequency of 4 kHz.

III. RESULTS

Fig. 1 is an example from a recording during a voluntary contraction. The initial EMG response to a 20° stretch consists of a number of peaks, followed by a more tonic response [Fig. 1]. The latency of the peaks varied considerably from subject to subject, and often there appeared to be an overlap between peaks. In order to reveal the effect of background torque on the EMG response, the integral of a 40 ms time window commencing at the onset of response was calculated.

1) *Electromyographic results*: The onset of the RF stretch response had a latency of 46 ± 9 ms. In all subjects a second burst of activity commenced 150 ± 20 ms after stretch onset. For the remainder of the stretch the RF EMG remained above baseline level, until the stretch was released which was in most cases accompanied by a large decrease in RF activity.

Fig. 2 reveals that the amplitude of the first 40 ms of the stretch-reflex response is closely linked to the background torque, especially for the higher background torques.

2) *Mechanical results*: For the first 50 to 70 ms following the onset of the stretch, both the non-reflex torques as recorded during the electrical stimulation trails, and the total torque increment recorded during the voluntary contractions, exhibited the same pattern (Fig. 3). This similarity is in part due to the inertia of the moved platform, leg and foot segment [5].

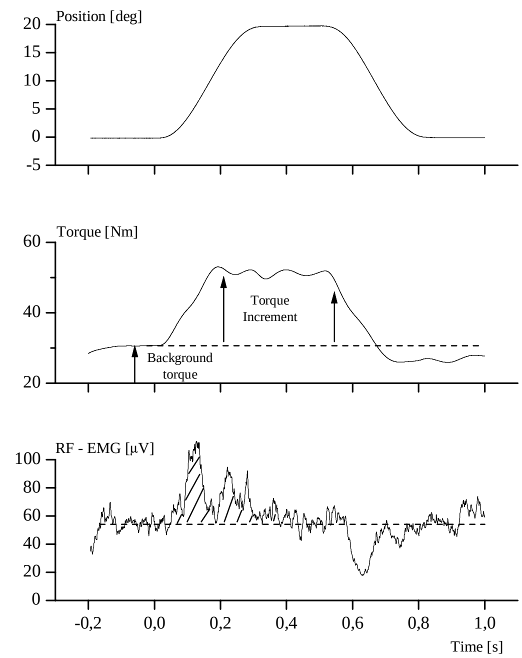

Fig. 1. Knee position, torque and rectified RF surface EMG averaged over 10 stretches.

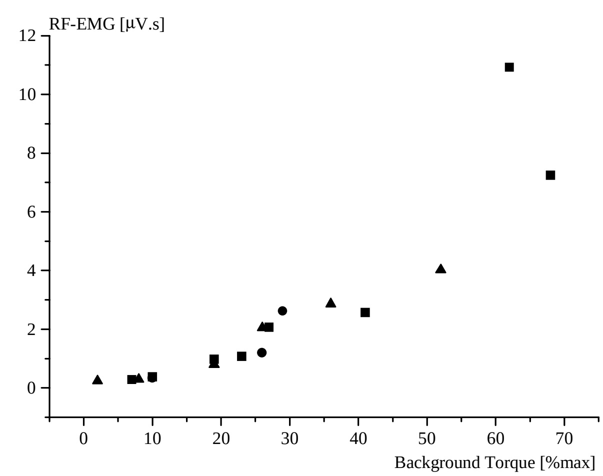

Fig. 2. RF stretch responses measured as an integral over a 40ms time window from the onset of the stretch in relation to background torque expressed as a percent of maximum voluntary torque. Each data point represents the average of 10 trials. Different signs indicate different subjects.

After this initial period, the non-reflex torque remained relatively stable whereas the total torque continued to increase until it reached its maximum at approximately 200 ms after stretch onset. Fig. 4 displays the reflex mediated torque in relation to the background torque at

300 ms after stretch onset.

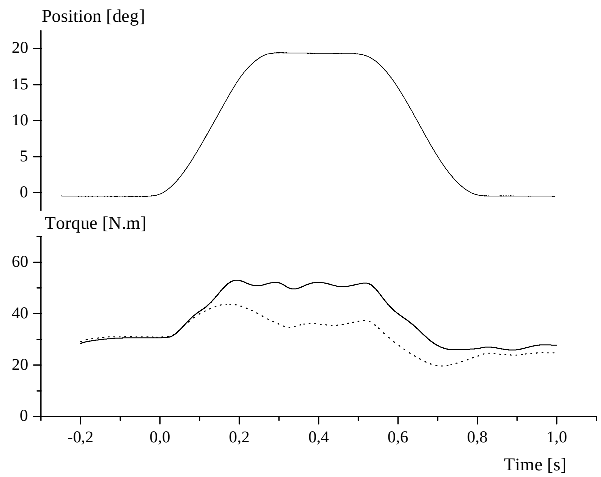

Fig. 3. Increments of total torque [-] and non-reflex torque [- -] in response to a stretch of 20° amplitude

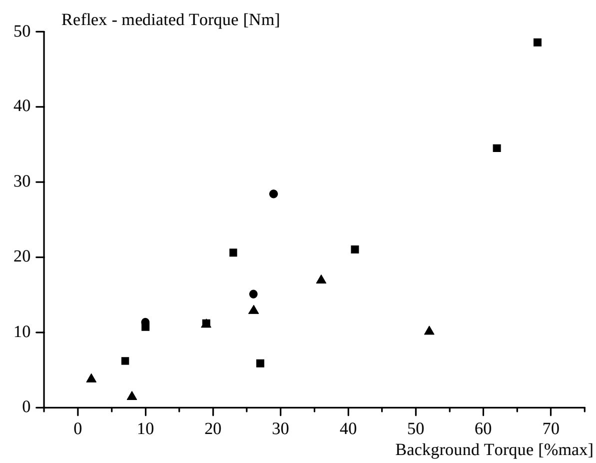

Fig. 4. Reflex–mediated torque in relation to background torque at 300 ms after the onset of the stretch. Different signs indicate different subjects.

Expressing the reflex-mediated torque as a percentage of the non-reflex mediated torque and averaging for all background torques, the subjects showed a reflex-mediated contribution of 150 to 350 % respectively.

IV. DISCUSSION

Only three subjects participated in this pilot study, which does not allow for any statistical comparisons. However, there is already, quite a strong and obvious trend in the predicted direction for both the mechanical and electromyographical responses to an imposed stretch at the knee joint with increasing background torques. It appears that the stretch reflex elicited in the RF has at least a similar potential for contributing to the overall stiffness of the knee joint as the ankle extensors have at the ankle joint. Functionally it is of importance to maintain the knee joint stiffness as stable as possible throughout a movement, especially as the muscles spanning it are very powerful such that any uncontrolled motion could lead to severe trauma.

Studies on the human ankle joint have revealed quite distinct peaks in the EMG response to an imposed stretch [1]. In this study, the knee joint was examined and these clearly defined peaks are not so evident here. This may simply be due to the closer proximity of the joint, and therefore the muscles, to the spinal circuitry, which may cause some of these responses to overlap. In addition, stretches performed in this study were much slower and of greater amplitude. Keeping in mind the rather limited number of subjects in this study, the integral increases with increasing background torques and in this case, levels of contraction. Thus the automatic gain principle as suggested by Matthews [12] appears to be verified at least for the RF muscle.

V. CONCLUSION

The reflex mediated torque was shown to increase with increasing levels of background torque, for the three subjects investigated. Depending on the subject, the reflex-mediated torque contributed on average 60 % to 80 % of the total torque. It is concluded that the short latency stretch reflex of the quadriceps muscle has the potential to contribute substantially to the torque produced at the knee joint.

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